R & D Plan for Superconducting Deflecting RF Cavity for Berkeley Ultra-fast X Ray Source

(Derun Li, February 20, 2002)

Issues need to be studied:

- What is the operation limit for $E_{max}/V_{transverse}$ or $H_{max}/V_{transverse}$? (Theoretically H_{max} is 240 mT, TESLA cavity has achieved 25 MV/m accelerating gradient which corresponding to 80 mT of H_{max}. Literatures indicate that E_{max} is typically the limiting factor for higher gradient operation due field emissions).
- What is the highest operational Q_{ext}? We should follow CEBAF upgrades work and collaborate closely with them.
- Multi-cell superconducting deflecting cavity design
  We need to understand the dispersion relations better to determine what is the best option for number of cells. Due to the flat dispersion curve near π phase, it is important to optimize coupling between cells with given number of cells. Cavity geometry optimization needs to be checked against multipacting simulations.
- Is normal conducting cavity an option?
  Preliminary studies (at 2.6 GHz) show very high peak and average powers are needed to meet the proposed requirements. It is estimated that about 32 MV/m peak RF power with duty factor of 3% (high!) is required.
- Deflecting mode is a TM_{110} like-mode, Lower-Order-Monopole-Modes (LOMs) will be excited by the beam. We need to calculate the effects of these LOMs may cause to the beam. Simulations on LOMs should tell us if we need to damp them or not.
- Power coupler? What's the highest CW power the coupler can handle? (Fermilab design claims for 400 watts of CW power at 3.9 GHz) We should carefully study available power coupler designs and make sure they meet our requirements.
- Computation of loss factors for all LOMs and HOMs
- Simulations of short range wakefield and loss factor? (It does not look like a problem for us now, but needs to be verified.)
- Synchronization study with laser and what issues are involved with the RF control system?
- Search for RF power sources at 2.6 GHz and 3.9 GHz, what output power klystrons are available at these frequencies and cost?
- Cryogenic issues: cryogenic system requirement for the deflecting cavity; cryogenic module design for the cavity (need helps of expertise from cryogenic engineers: people at Fermilab or Jlab).

- Superconducting cavity manufacturing, cleaning procedures and surface treatments.
- Low level RF control and high power RF system.
- Collaborations with experts at JLAB, Fermilab, DESY, … are important.
- Visits to Facilities at Fermilab, Jlab, DESY, Accel should help us to identify key issues we need to work on.

Current Status:

Literature indicates that R&D efforts on the SC deflecting cavities have been going on for over 10 years. However, no report has been found for operational superconducting deflecting RF cavities yet. Research work has been reported by KEK-B factory, Cornell University, and Fermilab recently. Among them, only the Fermilab reported a design for multi-cell cavity for Kaon separation experiment. The Fermilab design is a 13-cell cavity at 3.9 GHz with 5 MV/m deflecting voltage, which, if it works, should almost meet our requirements. Nevertheless LOMs and HOMs are needed to be studied for our application. Fermilab group have designed, fabricated and tested a single cell and a five-cell cavity with good agreements with simulation studies. The single cell cavity test already achieved 10 MV/m deflecting voltage, which corresponds to a peak surface electric field and magnetic field of 34 MV/m and 109 mT, respectively. However the five-cell cavity only achieved 1 MV/m due to field emission problems (It seems to me that the field emission may be the main limiting factor for higher gradient, NOT H_{max} on surface at 100 mT region). The highest reported surface peak electric field was 52 MV/m at 500 MHz (or 1.5 GHz) by Cornell University a single cell KEK-B factory cavity. Fermilab tests showed achieved Q_0 of obtained of $2x10^9$ with a designed external Q of $6x10^7$, which corresponds to a 65 Hz bandwidth.

Plans:

1. Propose to build a multi-cell (maybe 7- or 9-cell) superconducting deflecting RF cavity to study the issues addressed above. This includes design for the cryomodule of the cavity and the cavity should be tested with high power at either Fermilab or Jlab by taking advantages of their facilities. It is desirable that the high power test to be tested at LBNL if the budget allows (needs to build a high power test facility). With close collaborations with Fermilab and Jlab, it may take 2 to 3 years to finish the work.
2. Cavity design, LOMs and HOMs studies should be carried out at LBNL, and be finished within six to eight months.
3. Cryomodule and tuner designs should be done at LBNL with helps and collaborations with Fermilab and Jlab (need helps from engineers). I assume it may take six months to one year to design and build the cryomodule. Visit to facilities at Fermilab, Jlab, DESY, and Accel should help for the design work.
4. The cavity manufacturing, cleaning, surface treatments may take eight months to one year after the cavity design. Most of this work may be done by industry or at other national laboratories, but LBNL personnel involvement is important.
5. Cavity tuning should be done at LBNL (four months). [What I learned from: (a) single cell frequency measurement before e-beam welding; (b) bead-pull, frequency and dispersion measurement of the welded multi-cell cavity; (c) computer code to estimate which cell needs to be tuned based on the measured frequencies and field amplitude; (d) repeat this until the field distribution is flat, typically within 5 %; (e) cleaning and final assemble]
6. Polarization of the deflecting cavity (squashed shape or squeezing in one plane)
7. Final assembling needs to have a clean room, and may have to be conducted at Fermilab or Jlab.
8. High power test using vertical dewar at either Fermilab or Jlab (six months)
9. During the cavity design and construction periods, short (weeks) and long term (months) visiting work at Fermilab, Jlab, DESY should help us to gain experience of superconducting RF research and testing.